

QA/QC FOR MODULE PRODUCTION

1 INTRODUCTION

This document describes the module production quality assurance and quality control measures that will be employed to ensure that high-quality assemblies are produced with a minimum of loss, or repair effort, associated with processing steps at Fermilab. It is well understood that handling issues need to be continually assessed during the design and development of assembly tooling and personnel experienced in hands-on silicon detector assembly (physicists, engineers and technicians) are an integral part of the design team developing the tooling and procedures. Furthermore procedures and testing must be in place to quickly identify processing issues during production. This is particularly true in Run IIb where the time frame is short and the daily production rate is high. A failure to catch a processing problem for two weeks could result in the loss of roughly 10% of the detector modules. In order to alleviate this risk the procedures outlined below provide for testing of all parts immediately after all significant handling steps, with a lag of less than five days from the start of that handling step. At any time that one suspects a processing problem there is the possibility of an immediate electrical test. However, the main concern is a systematic source of damage that goes unnoticed.

Prior to the start of each module production phase there will be a 2 week training period for the technical staff that will be doing the work, followed by a production readiness review requiring the approval of the L2 managers for proceeding with the production. This will include a review of the written procedures and documentation to aid the assembly (e.g. assembly drawings, travelers etc.) and a list of the trained staff with the lead technician and responsible floor manager clearly identified.

All electrical tests described in this document are performed with the PC based Saseq Teststands described in:
<http://d0server1.fnal.gov/projects/run2b/silicon/www/smt2b/Testing/SaseqTS-Description.pdf>

1.1 Module production flow overview

This section provides a brief description of the module production. More details can be found in the Technical Design Report. The description below is for modules that will be used in L1-5, but the process will be quite similar for the L0 modules, with comparable controls in place. For each operation the relevant risk is listed and the elapsed time before this damage would be identified. The schedule below is aggressive, but all modules should undergo functionality tests within 5 days of the start of assembly.

Day 1: Sensors aligned on CMM and glued with hybrid

Risk: mechanical misalignment due to tooling failure – identifiable in 1 day

Risk: mechanical damage to sensors or hybrids – identifiable in 3 days

Day 2: Survey sensor alignment.

Risk: None.

Flip assembled module and add HV connection, Kapton, grounding

Risk: mechanical damage to sensors or hybrids – identifiable in 2 days

Day 3: Flip assembled module and wirebond.

Risk: mechanical damage to sensors or hybrids – identifiable in 1 day

Place in storage box. Connect digital jumper cable.

Risk: mechanical damage to sensors or hybrids – identifiable in 1 day

Day 4: Debugging of completed module.

Risk: Electrical damage to hybrid or sensors – identifiable immediately

At this point the modules are ready for burn-in. The burn-in cycle time is three days so some modules will be stored for a few days prior to burn-in. The burn-in testing carries little risk to the modules, as there are extensive interlocks, fusing of supply power etc. to avoid accidental damage from equipment failures or operator error. Furthermore any damage of this type would be immediately apparent.

There is a similar sequence of events with regard to installation of modules on staves with only one day of elapsed time between each mechanical operation and the subsequent electrical testing that would reveal processing problems.

Day 1: Install axial modules on stave core, including ground connections

Risk: mechanical misalignment due to tooling failure – identifiable in 1 day

Risk: mechanical damage to modules – identifiable in 1 day

Day 2: Survey axial module alignment

Risk: None

Electrical test of axial modules

Risk: Electrical damage to modules – identifiable immediately

Flip stave core with axial modules

Risk: mechanical damage to modules – identifiable in 1 day

Install stereo modules on stave core, including ground connections.

Risk: mechanical misalignment due to tooling failure – identifiable in 1 day

Risk: mechanical damage to modules – identifiable in 1 day

Day 3: Survey stereo module alignment

Risk: None

Electrical test of stereo and axial modules

Risk: Electrical damage to modules – identifiable immediately

Day 4: Install C-channels on stave

Risk: mechanical damage to modules – identifiable in 1 day

Day 5: Electrical testing of completed stave.

Risk: Electrical damage to hybrid or sensors – identifiable immediately

Once completed, the stave package provides significant protection to the modules. Furthermore the staves will be stored in protective cases until they are to be installed in the support cylinders. As was done in Run IIa, a quick functionality test will be done on each module prior to installation of the stave to ensure that they are still functioning properly and that no damage has occurred since the previous tests. This test is also useful for establishing baseline noise measurements using the same test stand that will be used for testing the modules after they are installed in the support cylinders.

2 MODULE ASSEMBLY PROCESS

Information about the depletion voltage and the number of bad strips will be provided as input to the testing and assembly group and taken into account when choosing sensors for a particular detector module. The hybrids and sensors will already have undergone their QA/QC procedures and only “certified” parts will be used for assembly of modules.

The techniques for assembly of detector modules will be similar to those used in the past by many groups, including DØ. Sensors will be manually aligned with optical feedback from a camera mounted on a coordinate measurement machine (CMM). Once aligned, the sensors will be glued to one another, directly or via a connecting substrate. Reasonable expectations for this alignment are accuracy to a few microns. The hybrid will be glued directly to the silicon sensors in such a manner that the guard rings are not bridged by adhesive, to avoid any performance problems. Methods for this procedure have been prototyped successfully.

After this the module must be flipped to make the bias connection (HV) to the sensor backplane. Following this a Kapton foil will be bonded over the back surface of the module to isolate the HV from grounded carbon fiber structures in the staves. Ground connections from the hybrids that need to be positioned under the sensors will also be located at this time.

The module will be flipped again and wire bonding will then be done between the hybrid and the sensors, and from sensor to sensor for the modules with 20 cm readout segments¹. At several steps of the assembly sequence, the module will be electrically tested, repeating the short functionality test. Malfunctioning modules at any step of the assembly sequence will be sent to the repairs team for diagnosis and repair. Any systematic problems will immediately trigger a cessation of the production until the source of the problem is identified and a remedy found. Any such stoppage will require another readiness review with L2 management approval prior to resuming production.

¹ For the 400mm (20-20) modules, the sensor-to-sensor wire bonding can be done either before or after the hybrid is mounted. Sensor alignment and sensor-to-sensor wire bonding could therefore proceed prior to hybrid delivery, should that become a production constraint.

3 MODULE TESTING

At several steps during the assembly sequence, the module will be electrically tested, repeating the short functionality test described in the QA document for hybrids (NEED REFERENCE). In order to be able to read out the hybrid, a short digital jumper cable (testing cable) needs to be connected to the module. This will be done after assembly and wire bonding of the detector module, or when an electrical test is required. The connection of this testing cable needs to be done by a skilled technician, as it is a delicate operation that takes place with exposed wire bonds. The testing cable will remain attached to the module during the complete testing process until the module is installed in the tracker and the final jumper cable is connected. Malfunctioning modules at any step of the assembly sequence will be sent to the repair team for diagnosis and repair. We will consider the possibility that the individual modules may require cooling during the diagnostic tests to avoid over heating. Once a module has been assembled, wire bonded, and a testing cable has been connected, it will be stored in boxes similar to those used in Run IIa. These boxes allow for electrical testing, providing a path out of the box for the digital readout cable, ports in the base for dry gas purge, cooling of the sensors through the base plate of the box and a light-tight seal to allow biasing of the sensors. The modules will remain in these boxes through testing and burn-in and will only be removed when they are to be installed on the staves. Modules can be electrically tested by connecting the testing cable to the purple card, without opening the storage box.

3.1 Debugging of Detector Modules

Immediately after a detector module is produced, and before it is burned-in, it needs to undergo a functionality test, that we call “debugging”. The likelihood of damaging the detector modules during construction, in particular during wirebonding, is not negligible. An intermediate step between production and before module burn-in is needed to restore the functionality of the modules before performing any electrical tests. The steps we plan to follow during the debugging process are the following.

- Visual Inspection: A thorough visual inspection of the finished module will ensure that no mistakes were made during wire bonding and no mechanical damage occurred.
- Functionality test: this test is done on the module without applying bias voltage to the sensor to assure the electrical integrity of the hybrid after module production.
- Biasing of the detector: bias voltage is applied in 5V increments, monitoring the leakage current. Capacitors that might be broken during wirebonding will be identified during this step. Strips corresponding to broken capacitors will be disconnected from the readout electronics by pulling the wirebond between the silicon sensor AC bonding pad and the SVX preamplifier.
- Characterize the module by producing V-I and V-noise curves and determining the operation voltage.

We plan to have two 1-Saseq debugging stations in the Lab D clean room to check out modules as soon as they have been completed. With an average production for modules of about 30 modules per week, we would debug 3 modules per day in each station, which

provides ample time to work on modules that might have been damaged during production. If necessary, both debugging stations could be manned in two shifts, doubling the debugging capacity, which would allow us to match the planned maximum possible throughput of 60 modules per week.

3.2 Burn-in Tests for hybrids and detector modules

The burn-in test is part and parcel of the testing procedure for module production. It will be performed first on the stuffed hybrid after it has passed the initial functionality test described above. At this point the hybrids are subjected to long term readout cycles. The goal of the test is to select good hybrids for module assembly. The second burn-in test will be carried out after a module has been produced and it has passed the initial functionality test. The idea of the burn-in test is to run every component for a long period of time (up to 72 hours) under conditions similar to those expected in the experiment and monitor its performance, in particular, measure pedestals, total noise, random noise and gain and examine occupancy in sparse readout mode. Other parameters that will be monitored include temperature, chip current, and detector bias voltage and dark current measurement (in module burn-in only). Typical problems that are revealed by the burn-in tests are SVX chip failures, broken and shorted bonds, grounding problems, noisy strips and coupling capacitor failures.

We plan to set up two hybrid burn-in stations, with a capacity of 16 channels each, and two module burn-in stations, with a capacity of 32 channels each. This gives us a total capacity of 96 channels per burn-in cycle, which we consider adequate to accommodate an anticipated production rate of about 30 modules per week, with a maximum production capacity of 60 modules per week. For comparison, our production rate during Run IIa averaged 20 modules per week, and our burn-in capability was 32 channels. We expect to have two burn-in cycles per week, per station, on average. The large volume of information coming from the burn-in tests and the necessity to run the test for many devices requires the burn-in test software to be user friendly so that non-expert physicists taking shifts can operate the burn-in stations. The Run IIa software was based on a user-friendly Graphical User Interface written in the TCL/TK scripting language with the graphical toolkit in the Windows environment. This choice of software interface created a flexible system for performing a variety of tests using executables written in different programming languages, for data taking, monitoring and data analysis. We plan to reuse the Run IIa burn-in software, modifying it for our new modules, and reducing the amount of human intervention in processing the data and storing the information. Given the increase in our production rate compared to Run IIa, we will do most of the processing of data and storage of summary plots in the database automatically.

The different tests performed during burn-in are the following:

- Temperature sensor test: performed at room temperature, before the SVX chip is powered.
- Data integrity check: tests the stability of downloading the SVX chip and verifies chip identification number (ID) and channel numbers of the SVX data for each chip.
- Long term burn-in test: it consists of a number of runs with an idle interval between them in which the chips remain powered. In each run, the SVX chips are

tested in “read all” and “read neighbor” modes. In “read all” mode, chip pedestals are read out to evaluate the noise in each SVX channel and the chip calibration is performed. In sparse readout mode (“read neighbor”), where only the channels whose response exceeds the preset threshold and their immediate neighbors have to be read out, the frequency of false readouts is studied.

For detector modules, this test is performed with the module under bias. For a detailed description of the tests performed during burn-in in Run IIa, see DØ Note 3841. We plan to run the same tests during Run IIb. A Hybrid and Module burn-in run lasts typically 60 hours; the duration might be reduced as production progresses if no failures are encountered and a larger throughput is required.

3.3 QA Test for Detector Modules

Mechanically, all modules will be surveyed using the OGP, an optical CMM with pattern recognition that can quickly measure all of the fiducials on the sensors. This was done with the ladders in Run IIa. This measurement will also provide data on the flatness of the freestanding modules. The modules will be constrained to be flat during mounting on the stave core. The stave core with mounted hybrids is substantially stiffer than the individual components so that we expect to have very flat module assemblies in the finished staves. A number of completed staves will be inspected on the OGP to confirm that this is the case.

We plan to subject a small fraction (~10%) of detector modules to a thorough set of QA tests. The final set of tests will be developed once prototype modules are being produced. The current plan is to test modules in the following areas:

- Laser test: This test is meant to verify the response of the silicon sensor to a light signal. Detector modules will be placed on an x-y movable table enclosed in a dark box, biased and illuminated with a highly-collimated pulsed IR laser, providing a detailed test of each strip of the detector module in a functional setting. The same system was used during Run IIa. It is based on a 1-Saseq test stand, with the addition of the movable table, dark box, and Laser. The solid state laser operates at a wavelength of 1064nm, a wavelength chosen because the high resistivity silicon used in the detectors is partially transparent to it. The attenuation as a function of silicon thickness has been measured, resulting in an attenuation length of 206μm. This laser will thus test the whole depth of the 320μm thick detector and not just a surface layer. We plan to do a detailed scan of the modules to check for uneven response of the sensor to the laser.
- Temperature cycles: The cooling provided during burn-in is only meant to avoid mechanical and electrical damage to the modules. The modules will run at a temperature between 10 and 15C, depending on the number of chips. We consider that a detailed temperature cycle test, in which modules are read out and checked for mechanical integrity after being subject to temperatures of -10C, is desired.
- Probe testing: We do have the ability to probe test silicon sensors after they were assembled into modules, or to do detailed checks of signals in the SVX chips by means of a logic analyzer and a probe tip. We can use this tools for QA tests if

found appropriate once we gain experience during the R&D and pre-production phase.

- Pull Tests: we will test wire bonds on the hybrids and between hybrids and sensors on their pull strength during the R&D and pre-production phase, and might consider doing it in a small fraction of modules during production if needed.

3.4 QA Test for Stave Assembly

For the detector modules from Layers 2-5, two axial and two stereo modules will be mounted on a stave before the stave is inserted in the bulkhead. The stave assembly sequence is a 3-day process, with an intended average production rate of one stave per day. The stave production capacity is 2 staves per day. On the first day the axial modules are pre-tested and then aligned and glued to the stave core. While the adhesive is wet, a quick functionality test may be done to ensure that no damage was done to the modules during mounting. In Run IIa this was done, but there were few instances of problems not associated with recognized human error. The remaining problems were related to migration of conductive adhesive being used to mount the ladders, which will not be an issue in Run IIb where we will be using non-conductive adhesive. On the second day the axial modules will be tested, the stave will be flipped and pre-tested stereo modules will be mounted to the stave. On the third day the stereo modules will be tested and then the structural elements will be glued to the stave. After this the stave will be tested with simultaneous readout of all 4 modules. The module installation requires high precision optical feedback for alignment. We anticipate doing this work on the new Browne and Sharp CMM that has been ordered, or on the LK machine in Lab C. The other machine will be used for installation of L0 and L1 modules, which mount directly to the castellated cylindrical support structures.

3.5 Electrical Tests during Stave and Tracker Assembly

We plan to do two types of tests on the modules during stave assembly. Both tests will be performed using a 2-Saseq test stand located in Lab C, close to the stave assembly stations. The first test will be performed on individual modules, immediately before and after installation on the stave. The second test will read out the four modules simultaneously after installation on the stave, to check for cross talk and grounding problems. Layer 0 and 1 modules are not installed on staves, but are mounted individually on the support structure. We plan to perform the same two types of tests during assembly (single module and simultaneous readout of in this case 6 modules), using a 3-Saseq test stand located in LabC, close to the L0/L1 assembly station. The steps of the single module test will be specified following the procedure used during insertion of ladders into the Run IIa SMT bulkhead (see Ref. ²), and are summarized below:

² See <http://d0server1.fnal.gov/projects/run2b/Silicon/www/smt2b/Testing/testing.html> under Procedure for ladder Assembly into Barrels for the SMT

1. Temperature sensor check at room temperature: ensures that the temperature sensor on the module is working properly. This test is done before the chips are powered.
2. Download of SVX chips for data mode operation
3. Check channel and chip ID
4. Take 100 events in data mode. Check for uniformity of pedestals and noise level
5. Download of SVX chips for cal-inject mode operation
6. Take 100 events in cal-inject mode. Check for uniformity of pedestals and noise level
7. Bias the detector to the operation voltage (depletion voltage + 5V)
8. Repeat steps 2 to 6

After four L2-L5 modules are installed in one stave, or 6 L0/L1 modules are installed on one sector of the support structure, they will be connected and read out simultaneously, to check for crosstalk and grounding problems. Cooling of the modules during assembly and testing will be done with water at 3C. Details still need to be understood to minimize the number of times cooling is connected and disconnected during the assembly process.

4 SUMMARY

Drawing on the experience from Run IIa a comprehensive QC/QA program has been established to ensure that the rapid production required for Run IIb can proceed with minimal cost and schedule risk. Electrical testing steps are in place following each potentially risky mechanical operation, typically within a few days. This ensures that any systematic problems can be quickly identified and remedied before a significant number of parts are affected. Written procedures, training and readiness reviews are integrated into our plan at the outset to ensure production quality from the outset.